

# Ice

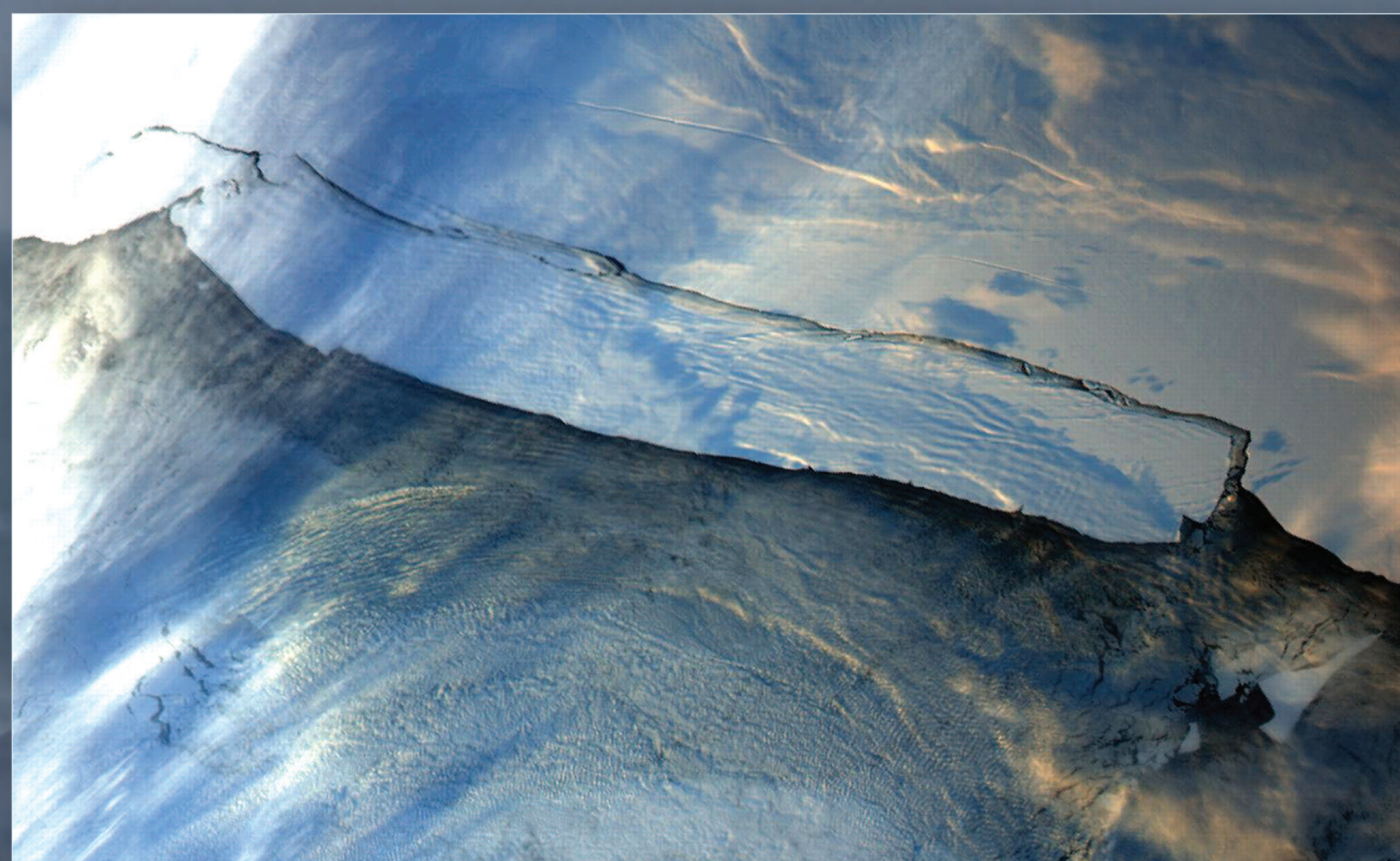
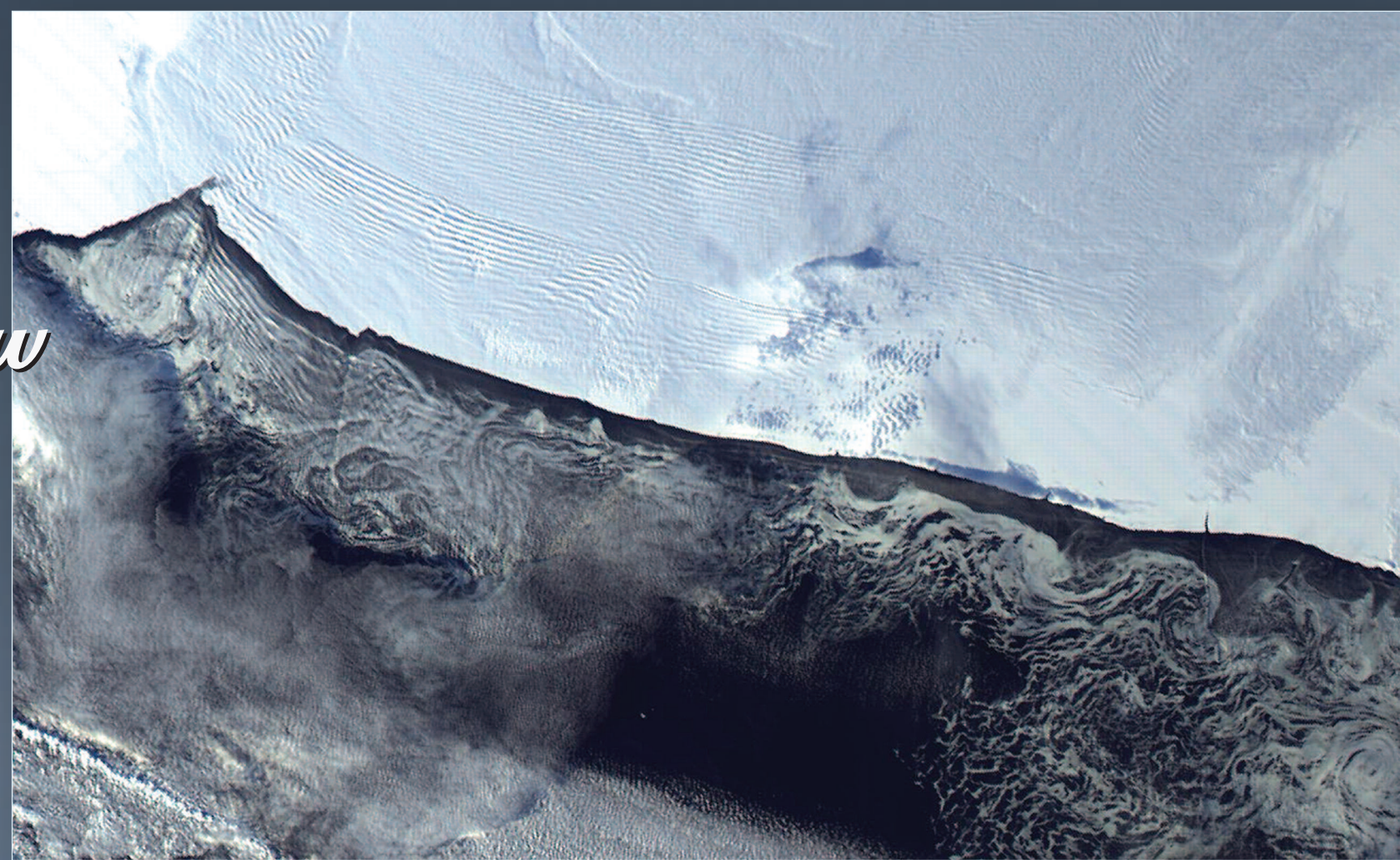
## Global Ice & Snow

### An Iceberg Nursery

Scientists who study global warming keep a close eye on new icebergs. Icebergs break off or "calve" at the edge of ice sheets. They range in size from small chunks of ice to vast ice islands. Large iceberg calving events only occur every few years, but their frequency appears to be increasing. Iceberg calving is a major way ice sheets return frozen water to the ocean.

The pair of Moderate Resolution Imaging Spectroradiometer (MODIS) images at the right shows icebergs in the Ross Sea that calved off the Ross Ice Shelf near Roosevelt Island, Antarctica, in March 2000. The upper image shows part of the Ross Ice Shelf prior to the calving of B-15. The image below shows B-15 in the process of breaking away from the ice shelf in March 2000. B-17, a comparatively small chunk, is observed in the upper left of the image, while B-16, a piece that calved in mid-March from the lower right near B-15, floats out to sea. The B-15 iceberg is one of the largest icebergs ever observed, with an area of 300 kilometers  $\times$  40 kilometers (186 miles  $\times$  24.8 miles), about twice the size of Delaware. The iceberg formed along cracks in glacier ice moving off the Antarctic continent.

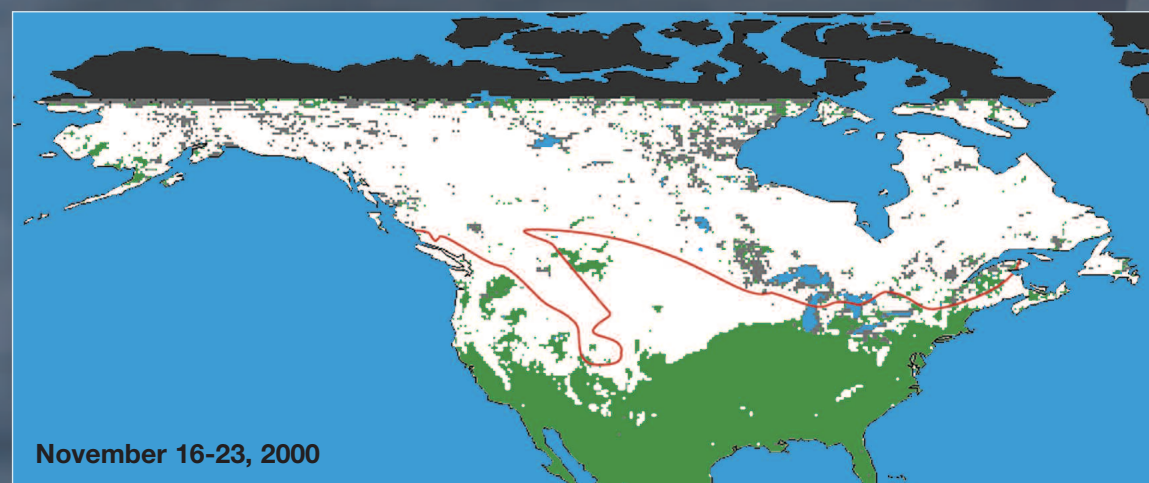
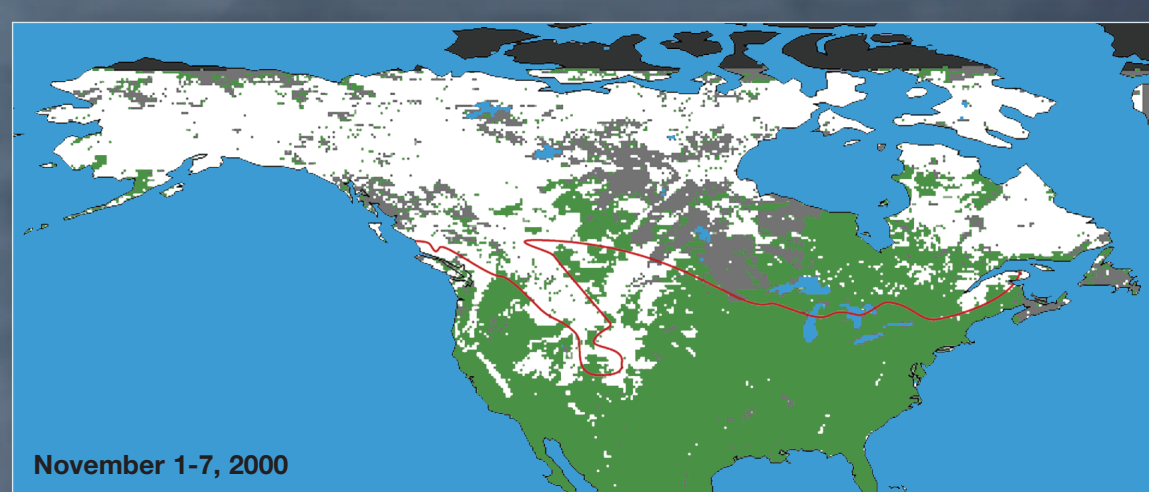
Images credit: Jacques Descloitres; National Snow and Ice Data Center; MODIS Land Science Team



Ice and snow profoundly affect our climate. During the Northern Hemisphere winter, they blanket up to 15% of the Earth's surface with a bright covering that reflects much of the Sun's radiant energy back to space. During the Southern Hemisphere winter, they cover about half this area.

An expected consequence of global warming would be a decrease in the Earth's snow and ice cover, which would increase the global absorption of solar radiation and, in the event of a significant melting of land ice, increase sea level. Satellite data provide one of the best ways to observe ice coverage and variability. Visible and infrared sensors provide high-resolution images under sunlit and cloud-free conditions, while microwave sensors provide spatially less-detailed observations under dark or light conditions and cloudy or cloud-free conditions.

### North American Snow Cover

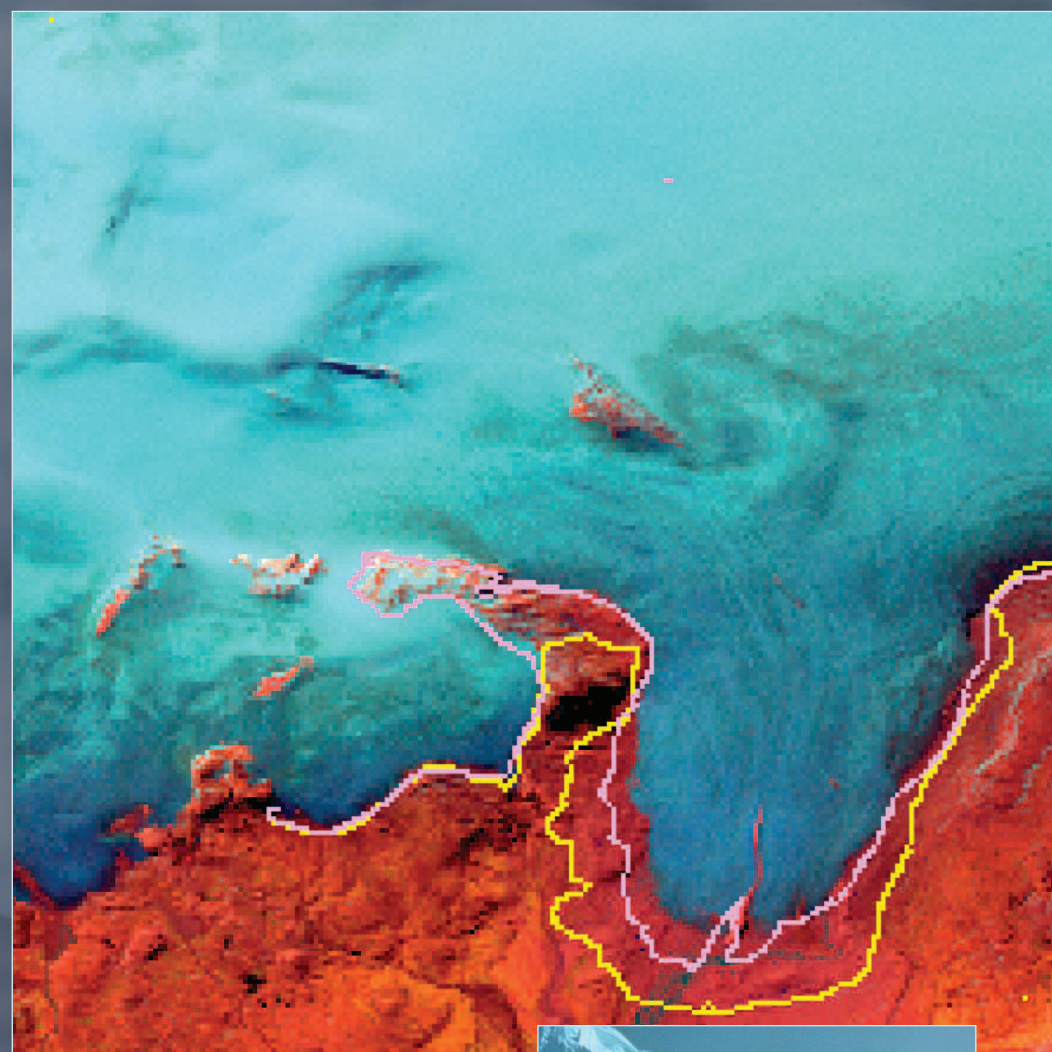


These snow maps of North America were created from data acquired by MODIS. They show the area in North America covered by snow (white pixels) as compared to the 35-year average November snowline (red line). Light gray pixels show areas covered by clouds for the entire period. Green pixels are land regions without snow, bluish pixels represent water, and dark gray pixels show areas where no data were collected.

Seasonal snow cover is vital to the water resources of many parts of the world. The amount and timing of snowmelt runoff is key to flooding and drought conditions in subsequent months.

Image credit: Dorothy K. Hall, Janet Y. L. Chien, Nicolo E. DiGirolamo, James L. Foster and George Riggs, NASA/GSFC

### Tracking a Glacier in Iceland



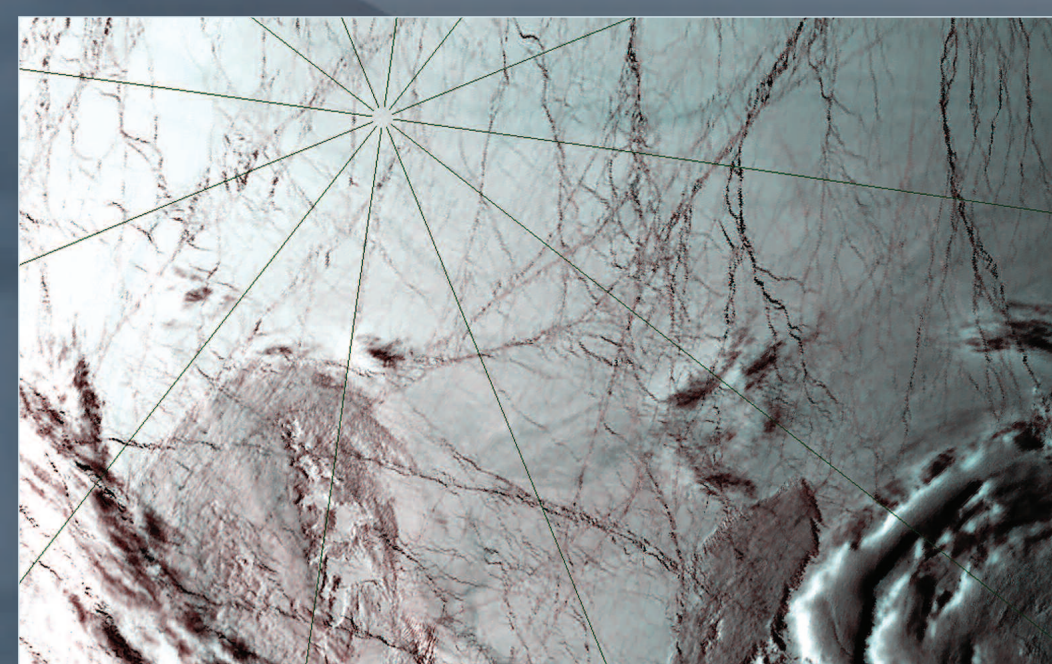
The false-color image at the left shows Eyabakkajökull, an outlet glacier of Vatnajökull, Iceland's largest ice cap. The image was acquired on September 23, 2000, by the Landsat Enhanced Thematic Mapper Plus (ETM+). Eyabakkajökull, a surge-type glacier, last surged in 1972-73. The yellow line shows the position of Eyabakkajökull at the time of acquisition of a September 22, 1973 Landsat Multispectral Scanner (MSS) image and the pink line shows its position in 1991. Those positions may be contrasted with its position in 2000, shown in the image. Since 1973 the margin of Eyabakkajökull has receded up to 1798  $\pm$  191 meters. Satellite tracking of glaciers began in 1972 with the first in the series of Landsat satellites. The rust-colored area in the bottom half of the image represents mostly vegetated terrain.

Image credit: Dorothy K. Hall, NASA/GSFC; Richard S. Williams, Jr., U.S. Geological Survey; and Janet Y. L. Chien, GSC/GSFC

The lower left inset photograph shows a 1974 glaciological expedition crossing the snow- and ice-covered Grimsvötn caldera lake and snow avalanche from the precipitous southeast wall of the caldera rim in Vatnajökull.

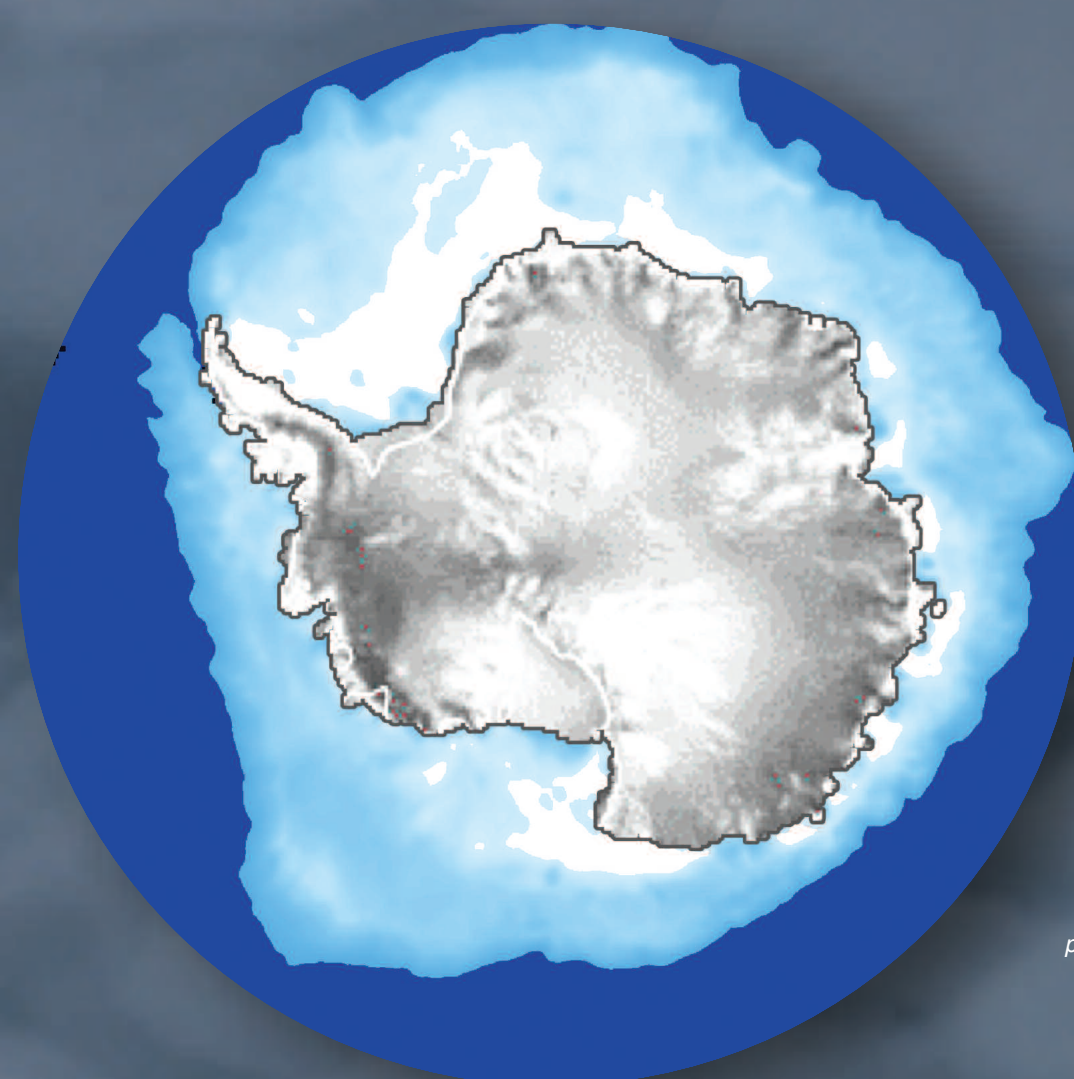
Inset image credit: Richard S. Williams, Jr., U.S. Geological Survey

### A Rare Look at the North Pole



The MODIS sensor offered a rarely seen glimpse of the surface of the Arctic Ocean north of the Arctic Circle. The area is usually shrouded in clouds but on May 5, 2000—a relatively clear day—this true-color image was acquired. The data were collected and processed by Norway's MODIS Direct Broadcast receiving station, located in Svalbard. Sea ice appears white and areas of open water (or recently refrozen sea surface) appear black. The dark irregular lines are cracks or "leads" in the sea ice. Leads are continually opening and closing due to shifting winds and ocean currents.

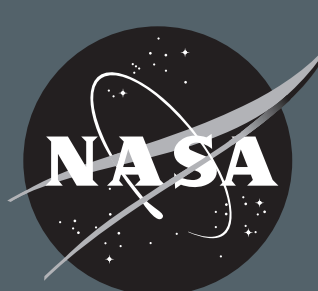
Image credit: Allen Lunsford, NASA/GSFC Direct Readout Laboratory; data courtesy Tromsø receiving station, Svalbard, Norway



### Wintertime in the Antarctic

The figure at the left combines sea ice information for September 1999 and land ice information for July 21, 1999. The deepest blue represents ice-free waters, with lighter gradations of blue representing waters with increasingly concentrated ice covers. White over the oceans represents waters nearly totally covered by ice (95% or more). The ice hinders transfer of heat between the ocean and the atmosphere and reflects much of the solar radiation that reaches it. The gray scale over the Antarctic ice sheet differentiates different kinds of ice. The sea ice information was derived from the Special Sensor Microwave Imager (SSM/I) on a satellite of the Department of Defense's Meteorological Satellite Program, while the land ice information was derived from the SeaWinds instrument on NASA's QuikScat satellite.

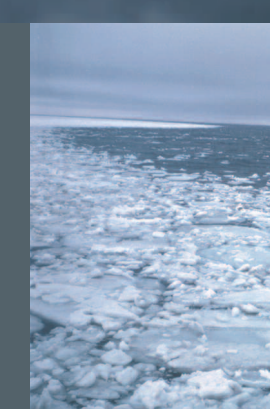
Image credit: Claire L. Parkinson, Nicolo E. DiGirolamo, and Donald J. Cavalieri, NASA/GSFC, for the sea ice portion; Tim Liu, NASA/JPL, for the land portion



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# Ice

## Global Ice & Snow

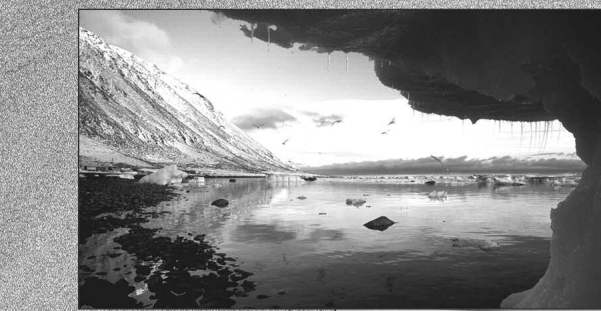


Image credit: Claire Parkinson

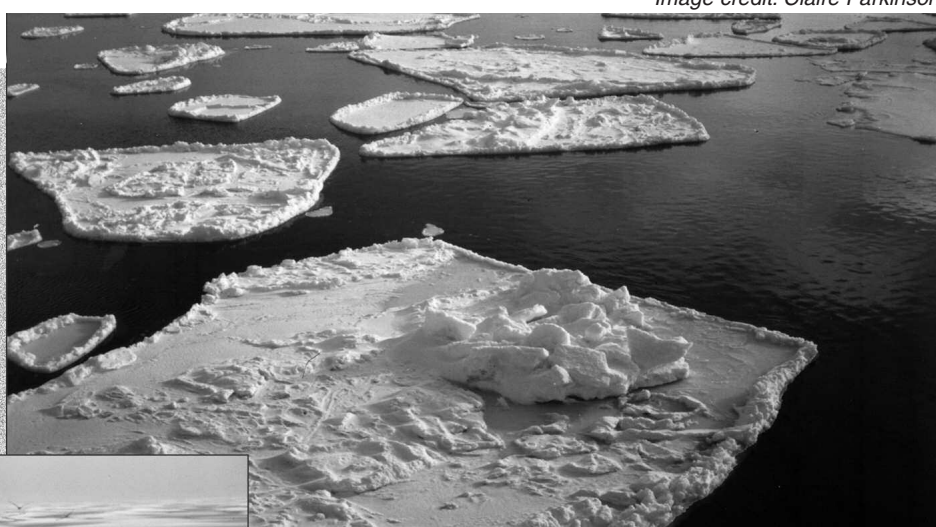
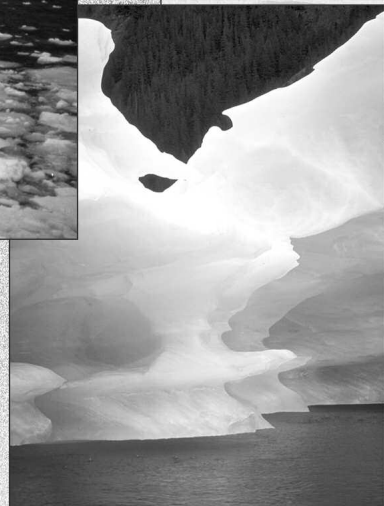
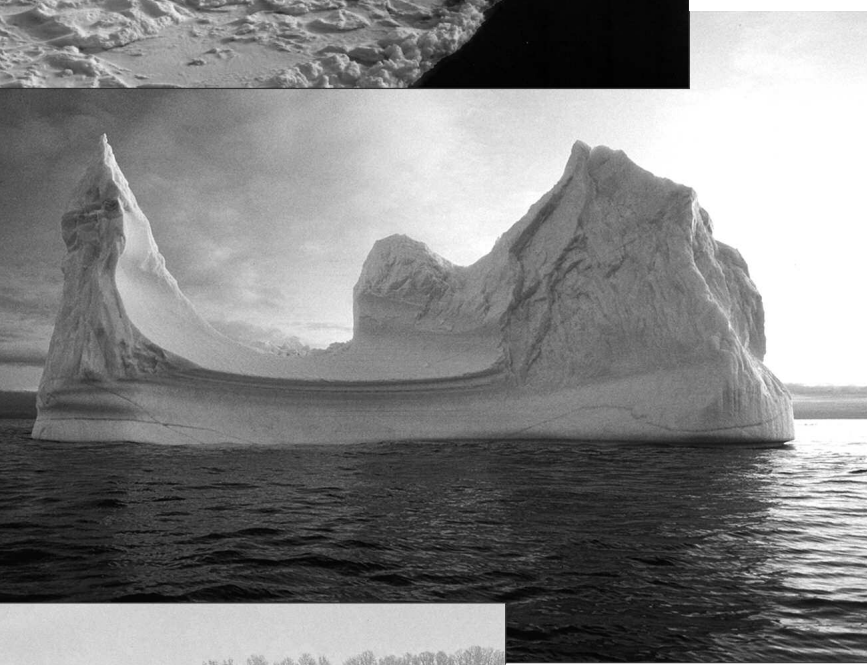
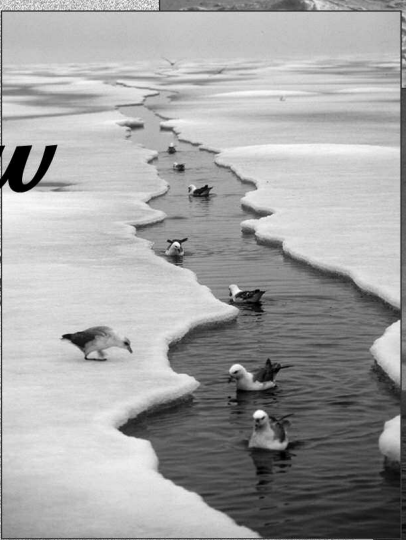


Image credit: Claire Parkinson



## Global Ice and Snow — A Mission Sampler

### Terra Mission

The Terra mission, launched in December 1999, carries five instruments, three of which provide significant contributions to snow and ice studies. These are the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), the Multi-angle Imaging SpectroRadiometer (MISR), and the Moderate Resolution Imaging Spectroradiometer (MODIS).

The primary goal of ASTER is to gather data in 14 channels over targeted areas of the Earth's surface, as well as black-and-white stereo images. With a revisit time between 4 and 16 days, ASTER will provide the capability for repeat coverage of changing areas on the Earth's surface with spatial resolutions of between 15 and 90 meters (49.2 and 295.2 feet). ASTER data, for example, will augment the Landsat database which was started in 1972, and together they will continue to provide scientists with the ability to determine the rates that glaciers are advancing or receding. Glaciers are sensitive indicators of changes in climate.

MISR measures the amount of sunlight that is scattered in different directions under natural conditions using nine cameras mounted at different angles. As the instrument flies overhead, each section of the Earth's surface is successively imaged by all nine cameras in four wavelength bands.

MODIS provides a comprehensive series of global observations every one or two days at spatial resolutions of up to 250 meters (820 feet). It provides the frequent observations necessary for multi-disciplinary studies of land, ocean and atmospheric interactions that enable us to understand more fully many of the critical issues affecting our environment. Amongst the variables being examined with MODIS data are glaciers, snow cover, and sea ice.

### Aqua Mission

The Aqua mission, launched in May 2002, carries six instruments, two of which provide significant contributions to snow and ice studies. These are MODIS, also on Terra, and the Advanced Microwave Scanning Radiometer for the Earth Observing System (AMSR-E).

AMSR-E monitors global snow and ice covers and a variety of other climate variables. The microwave measurements allow surface observations under dark as well as sunlit conditions and under most cloud-covered as well as cloud-free conditions, providing an all-weather capability for surface observations that is not available with visible and infrared imagery. The instrument was contributed to the EOS program by the National Space Development Agency (NASDA) of Japan.

### Landsat 7 Mission

Landsat 7 is the latest in a series of satellites that have provided a continuous set of calibrated Earth science data to both national and international users since 1972. Landsat 7 data have been used to monitor agricultural productivity, urban growth, and land-cover change, and are used widely for oil, gas, and mineral exploration. Other science applications include monitoring volcanoes, glacier dynamics, agricultural productivity, and coastal conditions. While other EOS instruments will acquire frequent, coarse views of land-cover change, the higher spatial resolution of data from the Enhanced Thematic Mapper Plus (ETM+) instrument on Landsat 7 may help researchers to determine the actual causes of observed land-cover changes. These changes have important implications, both for local habitability and for the global cycling of carbon, nitrogen, and water.

### QuikScat Mission

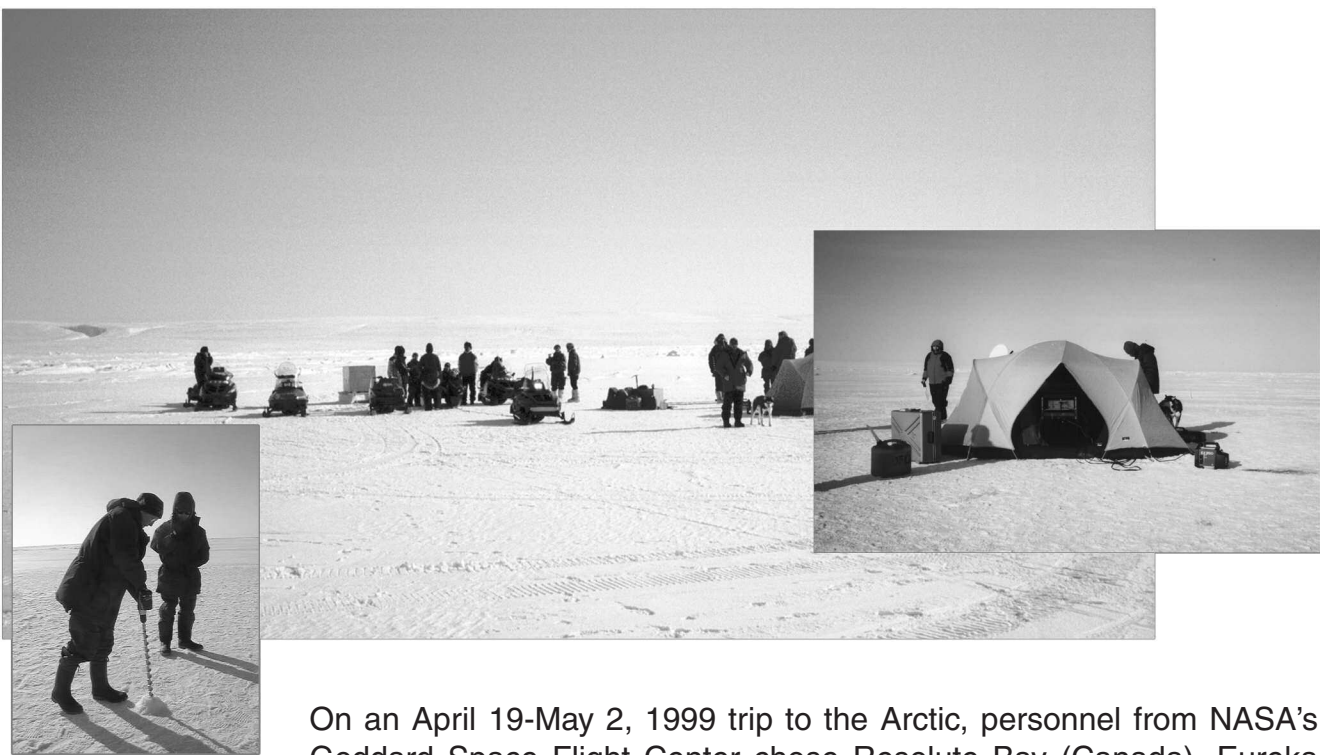
The QuikScat mission carrying the SeaWinds instrument was launched June 19, 1999. Its operation is expected to overlap the launch and validation of the SeaWinds instrument on ADEOS II (currently scheduled for launch in 2002). SeaWinds is designed to acquire high-accuracy wind speed and direction measurements over nearly 90% of the ice-free global oceans each day. As the only instrument capable of measuring wind velocity—both speed and direction—under all-weather conditions, SeaWinds measurements will be provided in near-real time for use in marine forecasting, operational global numerical weather prediction, and climate forecasting. SeaWinds data will also provide information for the study of sea ice and land ice cover and play a crucial role in interdisciplinary scientific investigations of wind-driven ocean circulation, air-sea interaction, and climate dynamics.

### ICESat Mission

The Ice, Cloud, and Land Elevation Satellite (ICESat) mission will measure the height of the Earth's polar ice masses, land and ocean surfaces, as well as clouds and aerosols in the atmosphere using advanced laser technology from a platform precisely controlled by star-trackers and the on-board Global Positioning System (GPS). ICESat's Geoscience Laser Altimeter System (GLAS) instrument was developed at the Goddard Space Flight Center, as part of NASA's Earth Observing System, and was launched on a Boeing Delta II rocket in January 2003. ICESat will determine if the great polar ice sheets are shrinking, and how these ice masses may change in future climate conditions. ICESat will also help us understand how clouds affect the heating and cooling of the Earth, will map vegetation heights, and will enable the most accurate maps of land topography to be produced. ICESat is designed to operate for 3 to 5 years and should be followed by successive missions to measure elevation changes for 15 years.

Pure water and moisture in air freeze to form ice at 0°C (32°F) but water that contains additional substances, like seawater, begins to freeze at lower temperatures. When water freezes it increases its volume by one eleventh. Geophysically this property is important as it causes ice to become less dense than the water from which it forms and thus to float on the surface of lakes and seas. This enables the development and survival of aquatic life in areas subject to seasonal freezing. The low density of ice is the result of the very open structure of ice produced by the highly regular tetrahedral net of water (H<sub>2</sub>O) molecules held together by hydrogen bonding. On melting, hydrogen bonds are broken, allowing the molecules to assume a more closely packed structure with an associated increase in density.

## A North Pole Expedition

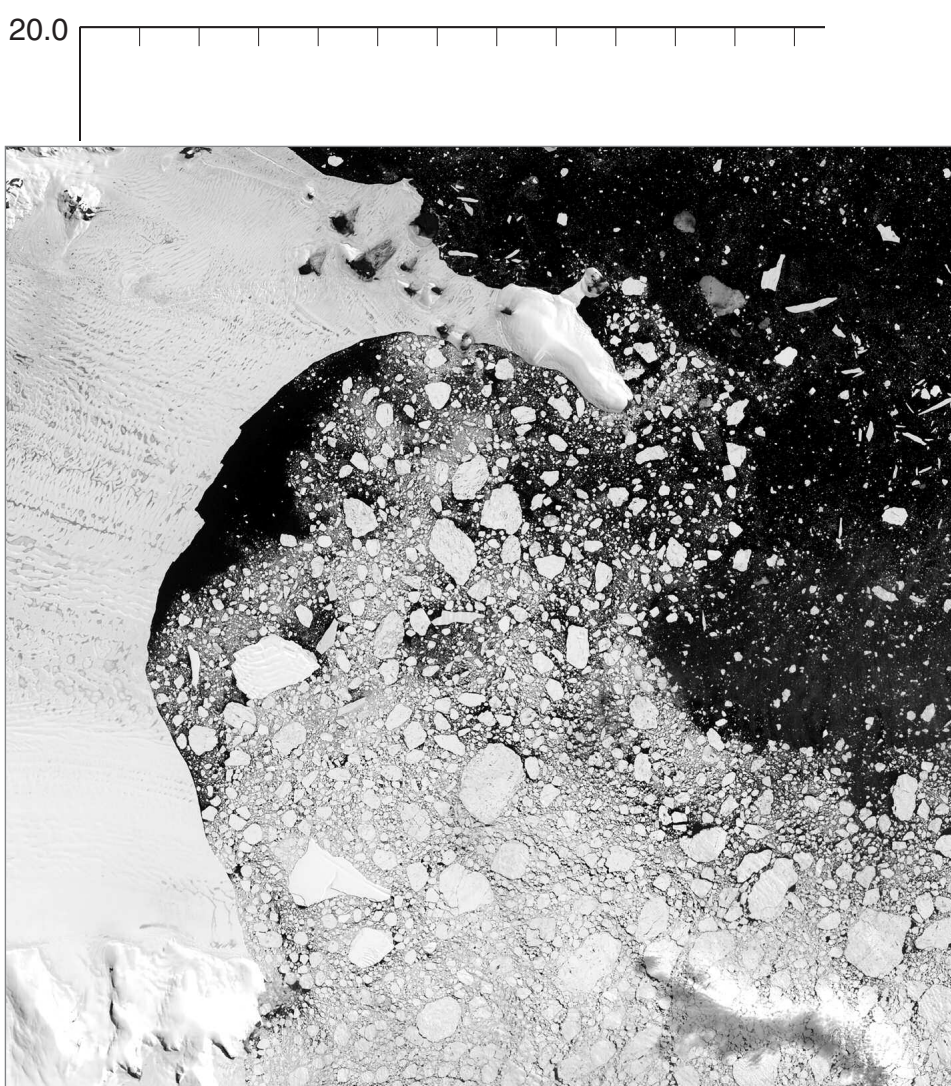


On an April 19-May 2, 1999 trip to the Arctic, personnel from NASA's Goddard Space Flight Center chose Resolute Bay (Canada), Eureka (Canada), and the North Pole as unique sites from which to demonstrate how new communications technologies and the Internet now make it possible for scientists working in very remote locations to send and receive data using NASA communications satellites. Amongst their accomplishments was the first ever live webcast from the North Pole.

During the expedition, the team demonstrated three new communications instruments that scientists can use while conducting field experiments: TILT (TDRS Internet Link Terminal), ECOMM (Early Communications), and PORTCOMM (Portable Communications). In addition, they collected ozone measurements with a hand-held Microtops photometer, Global Positioning System (GPS) measurements with a Trimble GPS Unit, and sea ice thickness measurements through holes drilled with both powered and manual ice augers.

A unique aspect of this expedition is that students from around the world interacted via their personal computers. The students could type in questions, then watch and hear as the personnel in the field answered.

Images courtesy of Steve Graham

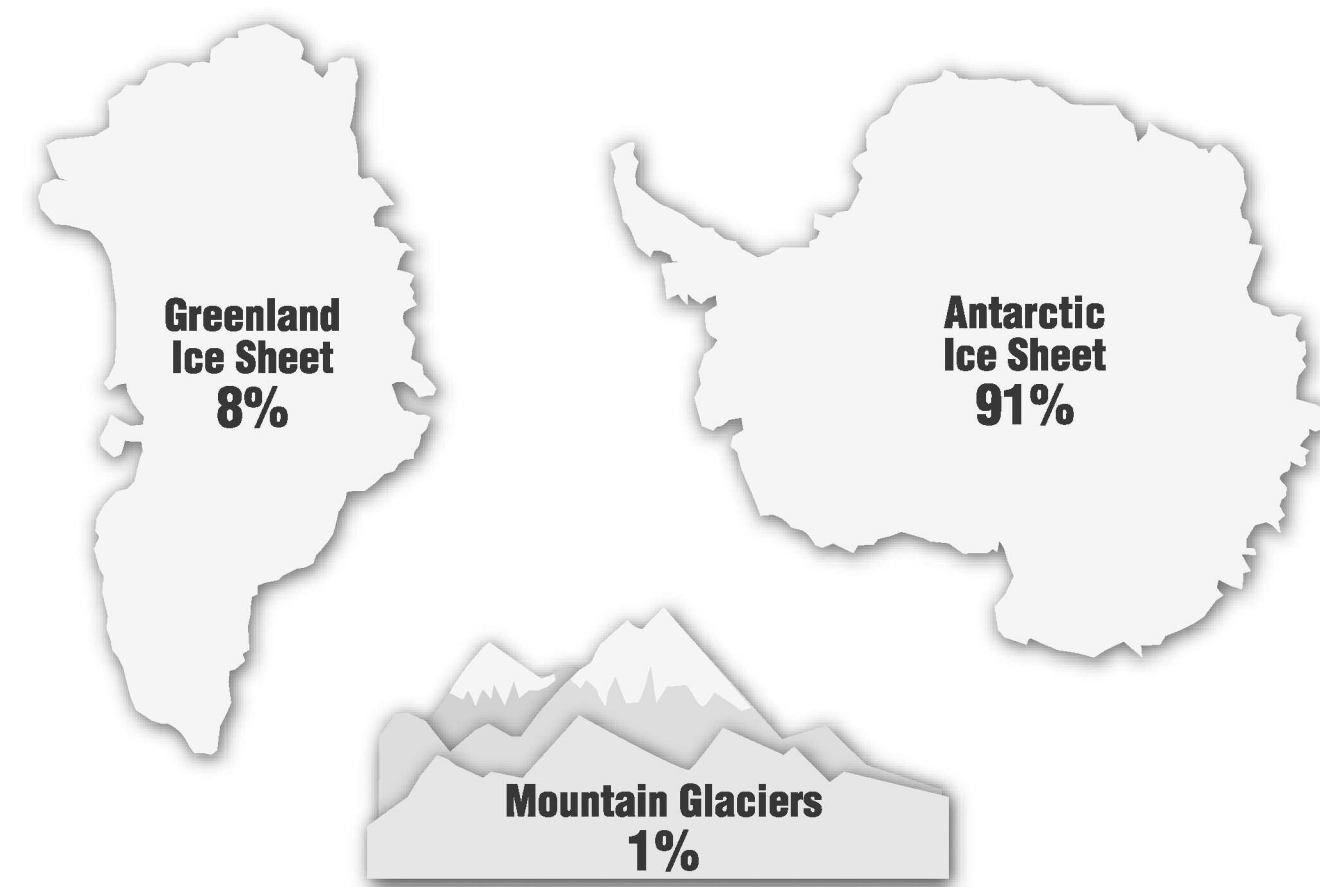


Along the edge of the Antarctic, warming surface temperatures can splinter an ice shelf and prime it for a major collapse. For instance, using satellite images that detect meltwater on the surface of the Larsen Ice Shelf and a sophisticated computer simulation of the motions and forces within an ice shelf, scientists have demonstrated that added pressure from surface water filling crevasses can crack the ice entirely through and permanently weaken the floating ice mass. The process can be expected to become more widespread if Antarctic summer temperatures increase.

This image from Landsat 7, acquired on February 21, 2000, shows a portion of the Larsen Ice Shelf and drifting icebergs that have recently split from the shelf.

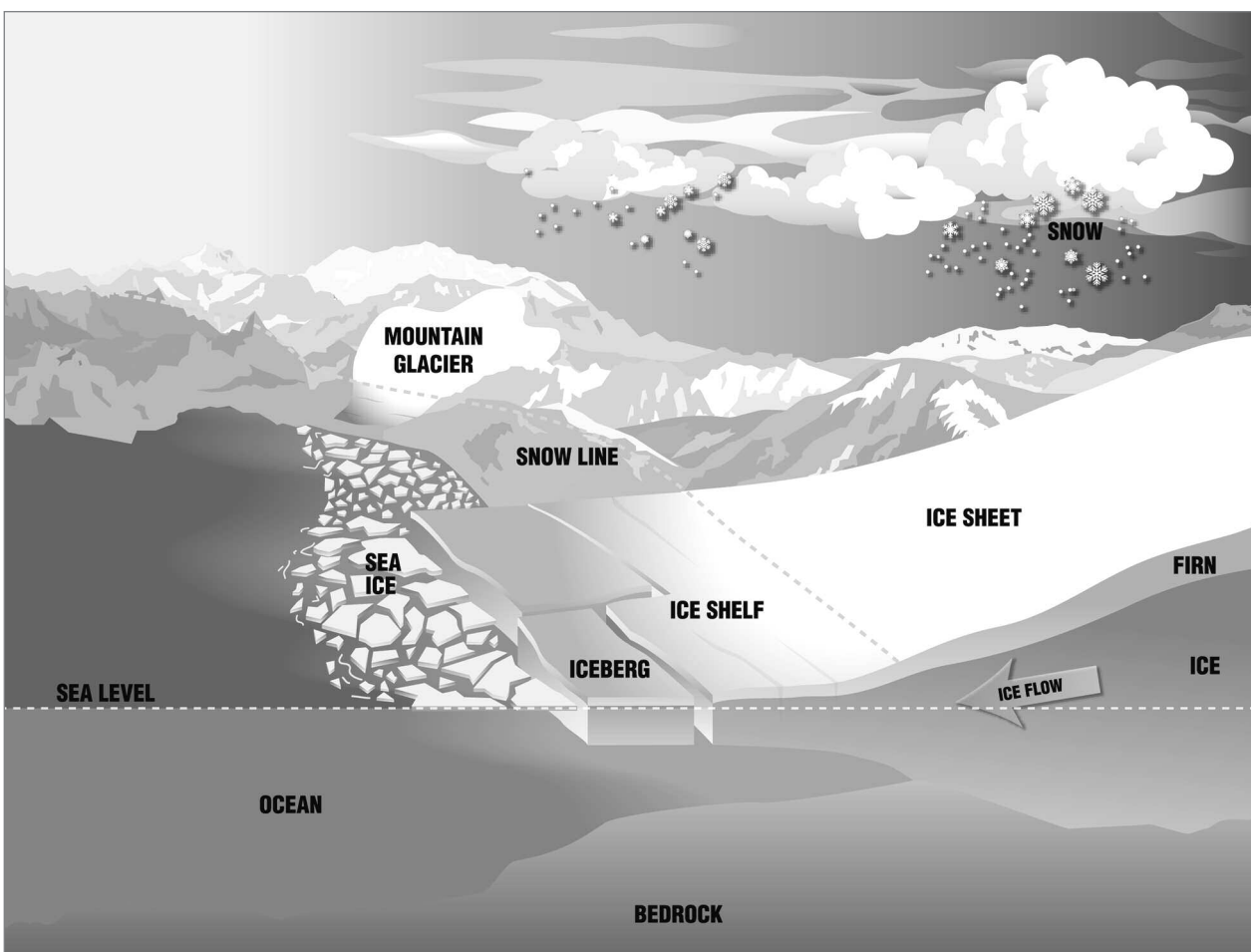
Image credit: Landsat 7 Science Team and NASA/GSFC

## Where's the Ice?



Over the past century, sea level has slowly been rising. This is in part due to the expansion of water as it warms and in part due to the addition of water to the oceans through either the melting of or the "calving" off of icebergs from the world's land ice. Many individual mountain glaciers and ice caps are known to have been retreating, and their melt and consequent runoff is contributing to the rise of sea level. Despite recent advances in measuring the mass balance of the world's ice, it is still uncertain whether the world's two major ice sheets covering Greenland and Antarctica have been growing, shrinking or staying the same. This is of particular importance because of the huge size of these ice sheets, with their great potential for changing sea level. Together, Greenland and Antarctica contain about 75% of the world's fresh water, enough to raise sea level by over 73 meters, if all the ice were returned to the oceans. Of this fresh water, approximately 91% is held in the Antarctic ice sheet, 8% in the Greenland ice sheet, and the remaining 1% in mountain glaciers which are found on every continent except Australia. Measurements of ice elevations are now being made by satellite radar altimeters for a portion of the polar ice sheets, and in the future they will be made by a laser altimeter on ICESat as part of EOS. The laser altimeter will provide more accurate measurements over a wider area. Changes in ice volume over time may indicate changes in the mass balance of the ice sheet.

The Greenland ice sheet is warmer than the Antarctic ice sheet and, as a result, global warming could initially produce more rapid melting on Greenland than in the Antarctic, where temperatures are far enough below freezing that, even with some warming, temperatures could remain cold enough over most of the continent to prevent extensive melting.

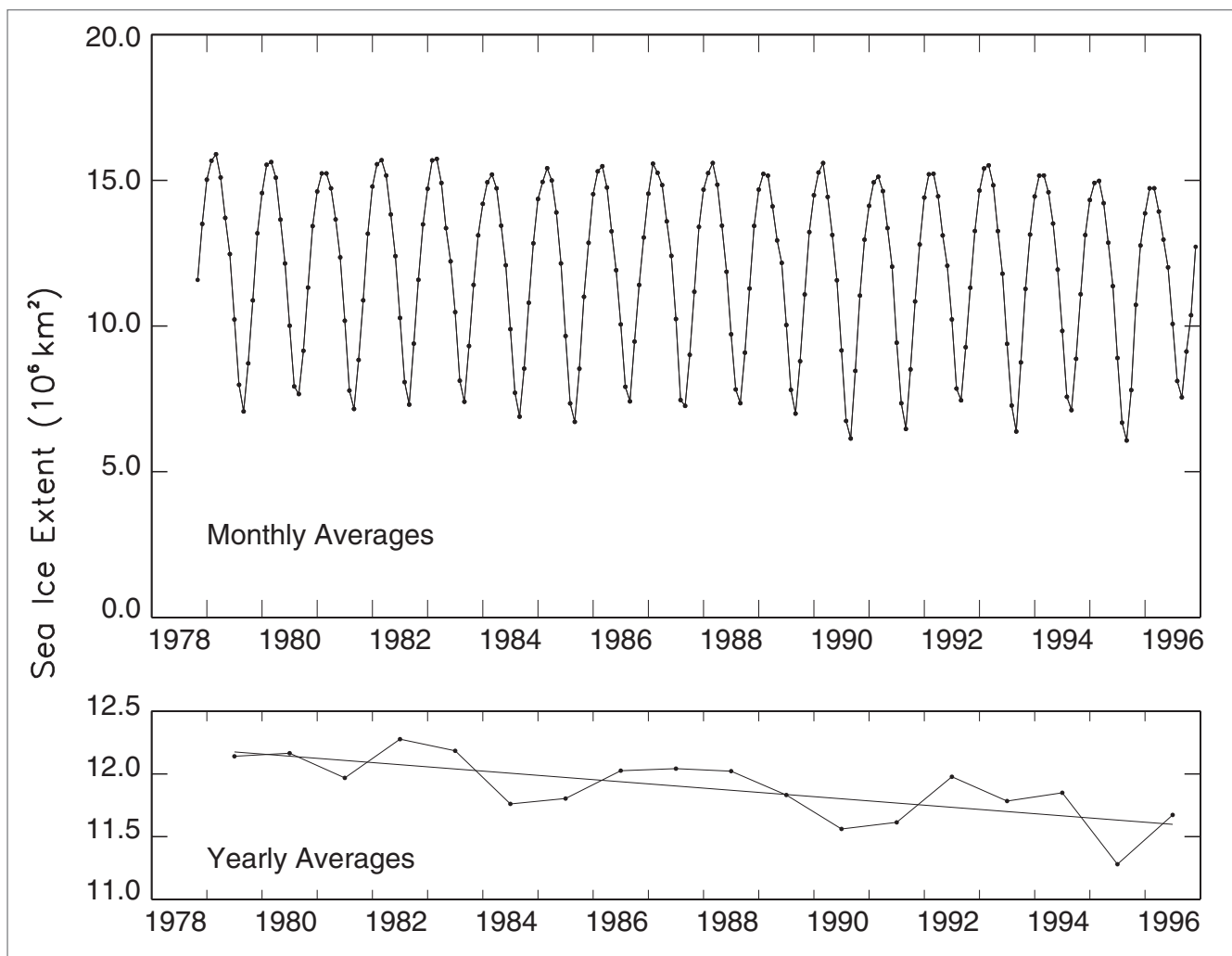


## For the Classroom...

Introduce major concepts of "Ice – Global Ice and Snow" by dividing the class into small teams to research several of the questions below. Students will research their answers using the poster and the Internet links found at the URL below. Students can prepare presentations to cooperatively instruct other teams using pre-established teacher criteria.

- Why do we use satellites to study snow and ice?
- What types of sensors are used and what are the advantages of each?
- Where is the greatest volume of ice in the world?
- How does changing land ice volume impact global climate?
- How do variations in sea ice and snow cover impact global climate?
- What is the difference between an iceberg and sea ice?
- How does seasonal snow cover impact water resources?

## Northern Hemisphere Sea Ice Extent



The plots pictured above show monthly average Northern Hemisphere sea ice extents from November 1978 through December 1996 and yearly averages from 1979 to 1996. The monthly averages highlight the strong seasonal cycle of sea ice coverage, from a minimum of about 7 million square kilometers (approximately 3 million square miles) in the late summer of each year to a maximum of about 15 million square kilometers (approximately 6 million square miles) in late winter of each year. Year-to-year differences, however, are also apparent. The yearly average plot includes a trend line and shows the uneven downward trend in the Arctic sea ice extents over this time period. The trend line has a downward slope of 34,300 square kilometers (13,200 square miles) per year. This suggests a loss of ice extent each year roughly equal to the combined areas of Maryland and Delaware. The values used in these plots were derived from data from the Scanning Multichannel Microwave Radiometer (SMMR) on board NASA's Nimbus 7 satellite and from the Special Sensor Microwave Imagers (SSMIs) on satellites of the Defense Meteorological Satellite Program.

Plot credits: Claire L. Parkinson, Donald J. Cavalieri, Per Gloersen, H. Jay Zwally, and Josefino C. Comiso, NASA/GSFC. The plots first appeared in an article by these scientists in the *Journal of Geophysical Research* in 1999.

## The Flow of Ice

Here you can see many of the basic forms of ice and snow and how they may be found in the environment. At high elevations or high latitudes, snow that falls to the ground can gradually build up to form thick consolidated ice masses called glaciers. Glaciers begin to flow due to their own mass and the force of gravity and can extend into areas which are too warm to support year-round snow cover. The snow line is the point below which all snow melts during the warmer part of the year. Snow that is beginning to turn to solid ice near the surface of a glacier is called firn.

The largest ice masses in the world are called ice sheets and are found in Greenland and Antarctica. Ice caps are smaller and may be found in places like Iceland and Patagonia. Both of these types of ice masses may have smaller outlet glaciers at their margins. Mountain glaciers, smaller than ice sheets or ice caps, flow from high mountain areas and are present on all continents except Australia. Where ice sheets reach the ocean and begin to float, the ice is called an ice shelf. Icebergs are floating ice masses that have broken away from a glacier or ice sheet. Sea ice is produced when saline ocean water is cooled to below its freezing temperature (approximately -2°C or 29°F), and this ice may extend on a seasonal basis over great areas of the ocean.

Sea ice and icebergs may also be carried by wind and currents into warmer waters. Meltwater from sea ice or icebergs does not contribute to sea level rise because these ice masses already displace an equivalent amount of sea water. However, sea level rise can be caused by the flow of additional glacial ice into the ocean and by surface or subsurface meltwater discharged from a glacier, as well as by expansion of warming sea water.



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For additional information on "Ice – Global Ice and Snow," consult the following URL: <http://nasadaacs.eos.nasa.gov/eosposters/>

# The Earth Science Enterprise

## The Earth Observing System

[eos.nasa.gov](http://eos.nasa.gov)

